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## (54) RECOVERING COMBUSTIBLE GASES FROM UNDERGROUND DEPOSITS OF COAL OR BITUMINOUS SHALE

(71) We, INSTITUT NATIONAL DES INDUSTRIES EXTRACTIVES, a Belgian Body Corporate, of Bois du Val Benoit, rue du Chéra, 4000 Liège, Belgium, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

The present invention relates to a process for recovering combustible gases from an underground deposit of coal or bituminous shale.

Traditional coal or shale mining operations have involved the sinking of access shafts and galleries from the shafts to the coal or shale face to allow access by workmen and removal of the products. Support must be provided at the face of the mine, and must be moved gradually as the mining operations progress. These methods are labour-intensive and have become unprofitable in many countries, so that large deposits of coal are no longer being worked.

In open-cast mining a layer of topsoil or rock is excavated to expose a deposit of coal or shale which can then be worked, for example, by mechanical shovels, dredger excavators or bucket-ladder dredgers. However, this method of working is appropriate only for a limited number of deposits occurring at relatively shallow depths.

For deep deposits, or where the potential yield of coal is insufficient to justify the excavation operations required for open cast mining, it has been proposed to convert the coal into a combustible gas *in situ*. The methods so far adopted have involved the drilling of a circulation path for air and gas comprising at least one air inlet bore, at least one gas outlet bore and at least one gallery connecting them. The circulation path has to be provided before the start of the gasification operation. In spite of a good deal of experimental work, this method has not met with general success on account of three major drawbacks:

(a) it has proved to be impossible to control the gasification process and to prevent air and gas escaping from the circulation path into the waste material produced during working;

(b) owing to lack of control of the gasification process carbon was converted to carbon dioxide rather than carbon monoxide; and

(c) it has proved impossible to carry out any rational working of a deposit in the form of stratified layers, and as a result in the majority of experiments only a small poriton of the deposit has been worked.

Several methods which attempt to overcome these difficulties have been devised. It has been proposed to perform the gasification by a cylcic process involving successively injecting under pressure air or a reactive gas such as hydrogen, allowing the gasification to proceed, and then allowing the gases produced to expand. A method for producing an extensive underground gas generating system in bituminous shale has been proposed using a nuclear explosion to supply the heat required to distil the bitumen permeating the shale and to provide fissures through which the gaseous distillate can pass. However, this method has not been tested, and its use is likely to be limited to desert zones because of the risk of contamination of phreatic strata with the radio-active byproducts of the nuclear reaction.

The present invention provides a process for recovering combustible gases from an underground deposit of coal or bituminous shale with overlying rock, in which coal or bituminous shale in a lower part of the deposit is thermally gasified, and the combustible gases thus produced are

recovered, whereby the overlying rock is heated, expanded and fissured to desorb and release combustible constituents therein which are recovered separately from but simultaneously with the said combustible gases. The process of the invention enables deposits of coal or bituminous schists at medium or great depths to be worked. It enables an underground gas-generating system to be produced without using a nuclear explosion and enables structures to be worked in which two or more superimposed layers of coal or bituminous shale are separated by intermediate layers of rock.

Gas of relatively low calorific value may be withdrawn from the thermal gasification zone in a lower strati-graphical level of the coal or shale deposit and may be used to produce electrical energy by the use of regenerative boilers and gas turbines. In an upper strati-graphical level of the deposit the rocks are heated, expanded and fractured so that fire-damp and other volatile materials present are desorbed and/or distilled and can be withdrawn as a gas of high calorific value. This gas can be purified and used as a substitute for natural gas or as a feed gas for chemical synthesis.

The process of the invention is particularly useful for the working of deposits of coal or bituminous shale which have not previously been worked. One or more gasification bores are sunk to the lower strati-graphical level of the deposit. A gasification chamber having a volume at least equal to the volume of the bore is formed surrounding the or each bore at the lower strati-graphical level. The gasification may be carried out by repeatedly injecting air or a reactive gas such as hydrogen under pressure into the gasification chamber or chambers, allowing the gasification reaction to proceed for the required time, and expanding and withdrawing the low calorific value gas produced. At the end of the injection step, the pressure in the gasification zone may be of the order of 40 to 100 atmospheres or even, if desired, above these values.

The layers of rock which may occur between various layers of coal or shale become heated to a high temperature by heat evolved during the gasification reaction, and act as a reservoir for heat. The heat retained in these rocks may be used to produce steam (which may be reacted with coal or bitumen to produce water gas), or, after the gasification operations have been terminated, for producing hot water which may be supplied to an electrical power plant or to an urban central heating system.

Figure 1 is a vertical sectional view through a coal-bearing deposit being worked according to the process of the invention.

A deposit of coal exists in the form of layers of coal separated by layers of rock. The deposit extends from an upper strati-graphical level $N_2$ to a lower strati-graphical level $N_1$. One or more gasification bores $S_1$ extend to the level $N_1$. One or more recovery bores $S_2$ extend to the level $N_2$. If the layer of rock above the deposit is highly porous and permits circulation and withdrawal of gases within it, the recovery bores need not be drilled further than this layer. If no such layer exists, it can be created artifically by the "fracking" method known in the oil-drilling industry. This method consists of injecting water to which sand and wetting agents have been added under a pressure which considerably exceeds the average pressure exerted on the layer by the weight of the overlying strata of rock.

If it is desired to obtain the maximum yield of gas of high calorific value, one or more supplementary bores $S_3$ may be drilled to intermediate strati-graphical levels. If required, a fracking operation is carried out for each supplementary bore.

The gasification bore or bores are desirably drilled down to a layer containing a significant amount of coal. At the base of the or each bore a gasification chamber C is provided, the volume of which is equal to or preferably considerably greater than the volume of the bore. This chamber may be formed by any suitable method, such as fracking, combustion, explosive pocket formation or hydraulic underwashing and pumping. In a layer of coal containing fire-damp (an "immediate release" layer) the combustion chamber may be formed by release of the pressure on the layer, the evolution of fire-damp being sufficient to cause fracturing.

The gasification and the recovery bores will each be lined with gas-tight metal tubes. For recovery bores, ordinary steel tubing may be used. For gasification bores at least the lower portion thereof between the strati-graphical levels $N_1$ and $N_2$ are lined with a refractory steel containing a high proportion of chromium and nickel and able to resist temperatures of the order of 1200—1300°C. Particular care is required to ensure a gas-tight seal between the ground and the upper part of the tubing of the gasification bore or bores to prevent escape of high-pressure gas. Allowance must also be made for thermal expansion and contraction movements of the tubing as a result of variation in temperature during various stages of the gasification process.

The required gas-tight seal may be formed, for example, using a layer of refractory cement having a low coefficient

of expansion of the kind which is used in the building of chimneys for industrial furnaces. This seal is slightly above the level $N_2$, and over it is a great depth of tamping. The tamping is desirably a thermoplastic material which can soften and allow expansion or contraction of the tubing while at the same time preventing any escape of gas. Suitable materials include, for example, asphalt, tar-bitumen, or a synthetic resin. At the top of the bore $S_1$ is an inlet tube having a valve A for injection of an oxygen-containing gas supplied under pressure from a compressor (not shown), and an outlet tube containing a valve B for withdrawing gaseous product, which is passed to a purification plant and then to a turbine (not shown). The gasification tube or tubes $S_1$ are advantageously provided with a fine internal tube (not shown) having means, for example one or more thermocouples, for measuring the temperature in the gasification zone and means for injecting water, oil, a combustible gas or oxygen in accordance with the temperature measurement to adjust the temperature in the gasification zone.

To start the gasification operation, a layer of coal or shale in the combustion chamber adjacent the bore $S_1$ is ignited. Various ignition devices may be used, for example electrically induced combustion of a charge of black powder or fracture of an incendiary capsule containing phosphorus. After ignition, the bore $S_1$ is closed, and progressively pressurised by compressed air (enriched, if desired, with oxygen) introduced via valve A. When the pressure has reached the desired value, which will normally be the maximum attainable value of which the compression plant is capable, valve A is closed, and the bore $S_1$ is maintained hermetically sealed for a suitable period to allow homogenisation of the gaseous masses injected into the gasification chamber. After this period of "digestion", the combustible gas produced is withdrawn and passed via valve B to the purification device for removal of dust and other harmful impurities and then to the expansion turbine. A second gasification cycle is initiated by introduction of a further quantity of air or a reactive gas, and the gasification process is continuously carried out with alternating injection of air or reactive gas and withdrawal of combustible gas.

In each cycle part of the coal is converted into gas, so that there is a progressive increase in the volume of the gasification chamber at the base of the bore $S_1$. The chamber therefore constitutes an empty space of gradually increasing volume, whose expansion causes a subsidence of the layers of sedimentary rock immediately above. The gasification chamber develops a naturally vaulted dome-shaped roof. When the gasification chamber reaches a sufficient size, the layers of rock which form its roof disintegrate and collapse, so that blocks f coal or rock accumulate on the floor. Fissures develop in rock and coal layers above the gasification chamber, and release of pressure on the overlying coal layers gives rise to a significant release of fire-damp by desorption from all the major and minor veins of coal in the massif of the coalfield.

In the process of the invention, this collapse phenomenon is helpful rather than a disadvantage. The blocks of coal and rock on the floor of the gasification chamber are highly permeable and do not substantially reduce its useable volume which is constituted by the interstices between the blocks. In previously known processes the collapse phenomenon resulted in inefficient use of air or reactive gas because of formation of alternative channels through cold zones away from the gasification chamber. In the present process these difficulties are avoided because of two factors:

(i) in virgin deposits the coal-bearing strata are highly impermeable to gas, and their impermeability is increased by compression of the domed roof of the gasification chamber, which behaves as a tight envelope capable of retaining the gas produced under a high pressure;

(ii) in the interior of the gasification chamber there is highly efficient heat transfer between the gases and the collapsed rocks partly because of the high pressure therein and partly because of the cyclic nature of the gasification process which gives rise to repeated contact between the rocks and the hot gases during each period of compression and each period in which gas is withdrawn.

The whole gasification chamber becomes heated to a high temperature as gasification proceeds, and as the chamber expands, small veins of coal situated in the roof are ignited, and subsequently the next stratigraphical layer of coal is ignited, so that the gasification reaction can spread from layer to layer.

A heap of incombustible rocks accumulates on the floor near the foot of the gasification bore and acts to some extent as a heat exchanger. It preheats the air or reactive gas during the periods of injection and cools the combustible gas being withdrawn. This heat-exchange effect enables a very high temperature to be maintained in the gasification chamber and a lower temperature, which is more readily

withstood by the metal tubing, in the vicinity of the gasification bore.

For smooth control of the process it is desirable to provide means for controlling the temperature all along the gasification bore, and means for increasing or decreasing the temperature. There is therefore provided in the gasification bore a tube of small diameter bearing a plurality of thermocouples fixed at different levels for measuring the temperatures prevailing between the strati-graphical levels $N_1$ and $N_2$. If the temperature rises too high, water can be injected through the small tube to lower the temperature by evaporation and by endothermic formation of water gas by the following reactions:

$$H_2O+C \rightarrow CO+H_2$$

$$2H_2O+C \rightarrow CO_2+2H_2$$

If the temperature is too low, it may be increased by injection of oxygen. Oil or a combustible gas may be injected if analysis of the product gas reveals a temporary deficiency of carbonaceous material. In general the maximum temperature along the bore should be maintained at a value of about 1000°C which is convenient for carrying out the gasification reaction.

The expansion of the gasification chamber is accompanied by a progressive expansion of the zone of collapsed rock and by a progressive rise in the level of the domed roof. In Figure 1 the symbols $V_1$, $V_2$ and $V_3$ illustrate three successive positions of the roof as the reaction proceeds. As soon as the roof reaches a layer of permeable rocks or a fracking zone adjacent a recovery bore significant quantities of gas can be withdrawn from the bore. For recovery of the maximum quantity of gas of high calorific value a counter-pressure is maintained within the supplementary bore $S_3$ so that the fire-damp and distillation products originating from the upper strati-graphical levels of the deposit can be withdrawn from $S_2$ without too much gas of low calorific value rising from the gasification chamber.

The heat accumulated in the rocks in the lower strati-graphical levels adjacent to the gasification zone may advantageously be used to increase the amount of gas of high calorific value recovered. Thus, when the rocks have reached a sufficiently high temperature, injection of air or reactive gas can be discontinued temporarily and a cycle in which water or steam is injected may be interposed between two cycles of gasification with air. Contact with high temperature rock produces highly superheated steam which reacts with white hot coal to produce water gas and methane. If the pressure in the bore $S_3$ is lowered, water gas, methane and excess steam penetrate the layers of rock above the gasificati n chamber and assist in the degassing and distillation of volatile materials from overlying coal strata.

The bore $S_2$ can also be used to prevent the infiltration of high-pressure gas from the gasification chamber into the overlying coal or rock strata, and the bottom of the bore is maintained at a pressure equal to or less than atmospheric pressure for this purpose.

The gasification operation is continued until all the accessible combustible material between the levels $N_1$ and $N_2$ has been distilled or converted into low calorific value gas. A period of several months, or even years, may be required. At the end of the operation the gasification chamber is filled with caved-in rocks heated to a high temperature. In the final stage of working it is desirable to recover the heat from these rocks by injecting cold water through the bore $S_1$ and by recovering steam and hot water through the bore $S_2$.

Substantial amounts of energy can be recovered by the present process. For example, the gasification chamber may at the end of gasification be of a generally ellipsoidal shape; it may reach a height of 300 metres and extend horizontally for 200 metres. The volume of the chamber may reach 6.3 million cubic metres, corresponding to about 15 million tons of rock. The quantity of coal initially present in this volume of rock may be greater than 1 million tons, and the amount of energy available for recovery is of the order of $7\times10^{12}$ KCal. 20 to 25% of this energy may be recovered in the form of gases of high calorific value. 50 to 60% may be recovered in the form of low calorific value gases at a high pressure, and 20 to 25% is in the form of heat imparted to the rocks and may be recovered as hot water or steam.

The deposit will normally be worked in practice using a number of gasification bores. For most efficient use of the compression and expansion turbines the gasification bores are divided into two sets whose gasification cycles are out of phase so that an injection period in one set of bores corresponds to a withdrawal period in a second set of bores. The sets of gasification bores may be connected in parallel and may be drilled sufficiently close together that during working the gasification chambers of adjacent bores coalesce.

Figure 2 is a plan view of a concession showing the general arrangement of the gasification bores.

A line of bores consisting of a set $E_1$ and a set $W_1$ within a concession ABCD are each

connected in parallel by pipelines which extend to a central station G situated in the appr ximate centre of the coal deposit. The approximate extent of the gasification zone surrounding each bore is indicated by broken lines. The central station includes means for recovering gas of high calorific value, a compressor for air or reactive gas, and an expansion turbine for the high pressure low-calorific value gas recovered. A second line of bores is in preparation and comprises sets of bores $E_2$ and $W_2$ situated at a distance from the bores $E_1$ and $W_1$ such that a protective zone exists between them.

WHAT WE CLAIM IS:—

1. A process for recovering combustible gases from an underground deposit of coal or bituminous shale with overlying rock, in which coal or bituminous shale in a lower part of the deposit is thermally gasified and the combustible gases thus produced are recovered, whereby the overlying rock is heated, expanded and fissured to desorb and release combustible constituents therein which are recovered separately from but simultaneously with the said combustible gases.

2. A process according to claim 1, wherein one or more gasification chambers are provided in the lower part.

3. A process according to claim 2, wherein the gasification is carried out by repeatedly injecting air or a reactive gas under pressure into the gasification chamber or chambers and subsequently withdrawing combustible gas therefrom.

4. A process according to claim 3, wherein water or steam is injected between injections of air or reactive gas.

5. A process according to claim 3 or claim 4, wherein air or reactive gas is injected until the pressure reaches a value in the range of 40 to 100 atmospheres.

6. A process according to any preceding claim, wherein one or more gasification bores are sunk to a lower strati-graphical level of the deposit, one or more gasification chambers having a volume equal to or greater than the volume of the or each gasification bore is or are formed in said level, and one or more recovery bores are sunk to an upper strati-graphical level of the dep sit.

7. A process according to claim 6, wherein one r more supplementary bores are sunk to an intermediate level of the deposit.

8. A process according to claim 6 or 7, wherein a porous zone is formed by a fracking operation at one or more of the levels to which the recovery or supplementary bore or bores has or have been sunk.

9. A process according to any of claims 2 to 8, wherein the gasification chamber is formed by combustion, fracking, explosive pocket formation or hydraulic under-washing.

10. A process according to any of claims 6 to 9, wherein the bottom of the or each recovery bore is maintained at or below the atmospheric pressure.

11. A process according to any of claims 6 to 10, wherein a fine tube is introduced into the or each gasification bore, the tube having means for measuring the temperature in the gasification zone and means for injecting water, oil, combustible gas or oxygen in accordance with the temperature measurement to adjust the temperature in the gasification zone.

12. A process according to any preceding claim, wherein air or a reactive gas is introduced into a first gasification bore or set of gasification bores and combustible gas is simultaneously withdrawn from a second gasification bore or set of gasification bores.

13. A process according to claim 1, substantially as hereinbefore described with reference to or as illustrated in Figures 1 and 2 of the accompanying drawings.

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1454324 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

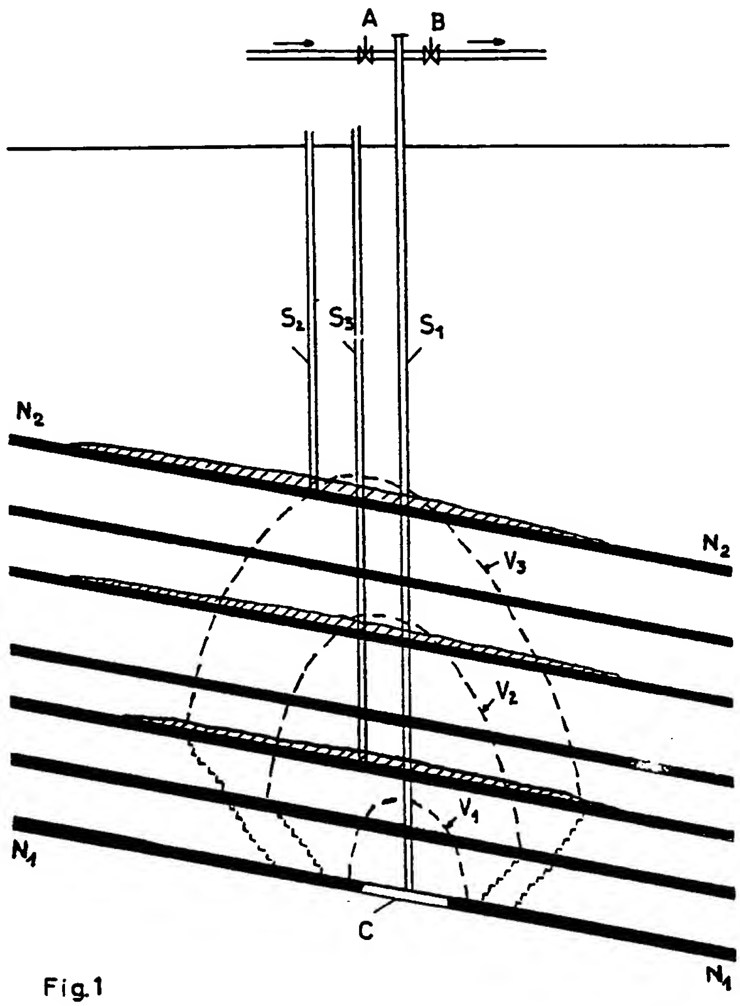


Fig.1

1454324 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

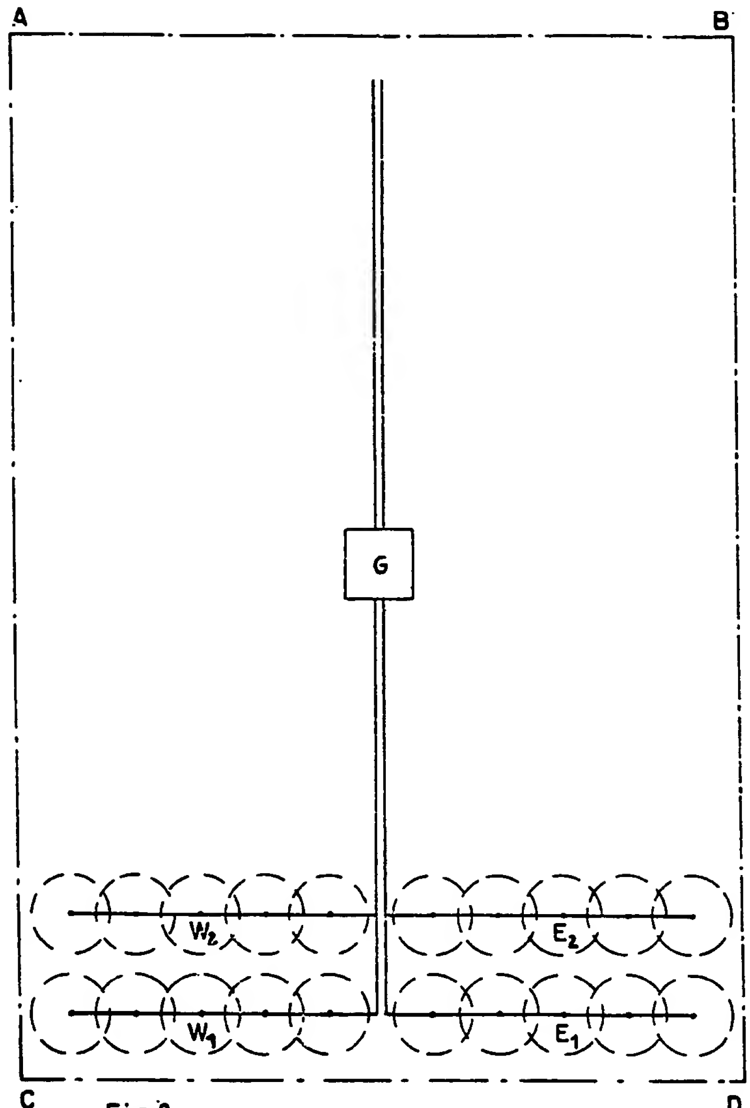


Fig.2